4.3.3.2.2.9 *Public and Occupational Health and Safety*

This section describes the radiological and hazardous chemical releases and their associated impacts resulting from either normal operation or accidents involved with disposal of immobilized Pu in a deep borehole complex. The section first describes the impacts from normal operation at the generic site, followed by a description of impacts from facility accidents.

For the public, the analysis includes an annual dose and cumulative risk to the maximally exposed individual, population, and average individual within 80 km (50 mi). For workers, the analysis includes an annual dose and cumulative risk to an average individual worker and total involved and noninvolved workforce. The health effects were derived from data for representative DOE sites described in Sections 3.2 through 3.7. Data for the representative DOE sites were used to allow qultification of impacts, but do not necessarily capture the entire range of potential deep borehole complex sites. This approach to the radiological risk assessment differs from the analysis of other resources, which are analyzed based on a generic deep borehole site. Because the analysis of radiological dose impacts requires site-specific conditions, such as meteorology and surrounding populations, a generic site analysis would not be possible because of the infinite number of site-specific conditions.

Summaries of the radiological impacts to the public and to workers associated with normal operation of the deep borehole complex during the assumed 10-year campaign time are presented in Tables 4.3.3.2.2.9–1 and 4.3.3.2.2.9–2, respectively. [Text deleted.] Impacts from hazardous chemicals to these same groups are given in Table 4.3.3.2.2.9–3. Summaries of impacts associated with postulated accidents are given in Table 4.3.3.2.2.9–4. Detailed results are presented in Section M.

Normal Operation. There would be no radiological releases associated with the construction of a deep borehole complex. Construction worker exposures to material potentially contaminated with radioactivity (for example, from construction activities involved with existing contaminated soil) would be limited to assure that doses are maintained as low as reasonably achievable. Toward this end, construction workers would be monitored as appropriate. Limited hazardous chemical releases are anticipated as a result of construction activities. However, concentrations would be within the regulated exposure limits. During normal operation, there would be both radiological and hazardous chemical releases to the environment and also direct in-plant exposures. The resulting doses and potential health effects to the public and workers are described below.

Radiological Impacts. Radiological impacts to the average and maximally exposed members of the public resulting from the normal operation of the deep borehole complex are presented in Table 4.3.3.2.2.9–1. The impacts from all site operations, including the deep borehole complex, are also given. To put operational doses into perspective, comparisons with doses from natural background radiation are included in the table.

The dose to the maximally exposed member of the public from annual operation of the deep borehole complex would range from 3.4×10^{-9} to 1.2×10^{-7} mrem. From 10 years of operation, the risk of fatal cancer to this individual would range from 1.7×10^{-14} to 6.0×10^{-13}. The impacts to the average individual would be less. As a result of annual operations, the population dose would range from 6.6×10^{-9} to 2.2×10^{-6} person-rem. The number of fatal cancers in the population from 10 years of operation would range from 3.3×10^{-11} to 1.1×10^{-8}.

The upper bounding dose of 3.2 mrem to the maximally exposed member of the public from annual total site operations is within the radiological limits specified in NESHAPS (40 CFR 61, Subpart H) and DOE Order 5400.5. The risk of fatal cancer to this individual from 10 years of operation would be 1.6×10^{-5}. The impacts to the average individual would be less. This activity would be included in a program to ensure that doses to the public are as low as reasonably conceivable. As a result of annual total site operations, the upper bound population dose would be within the limit proposed in 10 CFR 834, and would be 44 person-rem. The number of fatal cancers in this population from 10 years of operation would be 0.22.

Table 4.3.3.2.2.9–1. Potential Radiological Impacts to the Public During Normal Operation of the Deep Borehole Complex—Immobilized Disposition Alternative

Receptor	Generic Site[a]	
	Deep Borehole Complex	Total Site
Annual Dose to the Maximally Exposed Individual Member of the Public[b]		
Atmospheric release pathway (mrem)	3.4×10^{-9} to 1.2×10^{-7}	6.1×10^{-5} to 1.5
Drinking water pathway (mrem)	0	0 to 0.10
Total liquid release pathway (mrem)	0	0 to 1.7
Atmospheric and liquid release pathways combined (mrem)	3.4×10^{-9} to 1.2×10^{-7}	6.1×10^{-5} to 3.2
Percent of natural background[c]	1.1×10^{-9} to 4.1×10^{-8}	1.8×10^{-5} to 1.1
10-year fatal cancer risk	1.7×10^{-14} to 6.0×10^{-13}	3.1×10^{-10} to 1.6×10^{-5}
Annual Population Dose Within 80 Kilometers[d]		
Atmospheric release pathways (mrem)	6.6×10^{-9} to 2.2×10^{-6}	2.8×10^{-4} to 40
Total liquid release pathways (mrem)	0	0 to 4.7
Atmospheric and liquid release pathways combined (mrem)	6.6×10^{-9} to 2.2×10^{-6}	2.8×10^{-4} to 44
Percent of natural background[c]	7.2×10^{-11} to 8.3×10^{-10}	2.4×10^{-7} to 0.017
10-year fatal cancers	3.3×10^{-11} to 1.1×10^{-8}	1.4×10^{-6} to 0.22
Annual Dose to the Average Individual Within 80 Kilometers[e]		
Atmospheric and liquid release pathways combined (mrem)	2.2×10^{-10} to 2.5×10^{-9}	8.0×10^{-7} to 0.049
10-year fatal cancer risk	1.1×10^{-15} to 1.2×10^{-14}	4.0×10^{-12} to 2.5×10^{-7}

[a] Ranges for the "Deep Borehole Complex" and "Total Site" doses may not necessarily reflect the same respective sites. The total site values are applicable only if the deep borehole complex were located on DOE sites and would not apply if generic non-DOE sites were selected.

[b] The applicable radiological limits for an individual member of the public from total site operations are 10 mrem per year for the air pathways as required by NESHAPS (40 CFR 61, Subpart H) under the CAA, 4 mrem per year from the drinking water pathway as required by the SDWA, and 100 mrem per year from all pathways combined. Refer to DOE Order 5400.5.

[c] Annual natural background radiation levels: the average individual receives a dose that could range from 295 to 338 mrem; the population within 80 km receives a dose that could range from 9,190 to 379,000 person-rem.

[d] For DOE activities, proposed 10 CFR 834 (see 58 FR 16268) the potential annual population dose to 100 person-rem from all pathways combined, and would require an ALARA program.

[Text deleted.]

[e] Obtained by dividing the population dose at a site by the number of people projected to be living within 80 km of that site. The number of people ranges from 29,400 to 1,285,000.

Source: HNUS 1996a. Ranges are based on impacts from the following representative DOE sites: Hanford, NTS, INEL, Pantex, ORR, and SRS.

Doses to onsite workers from normal operations are given in Table 4.3.3.2.2.9–2. Included are involved workers directly associated with the deep borehole complex, workers who are not involved with the deep borehole complex, and the entire workforce at the site. All doses fall within regulatory limits.

Table 4.3.3.2.2.9–2. Potential Radiological Impacts to Workers During Normal Operation of the Deep Borehole Complex—Immobilized Disposition Alternative

Receptor	Generic Site
Involved Workforce[a]	
Average worker dose (mrem/yr)[b]	13
10-year risk of fatal cancer	5.2×10^{-5}
Total dose (person rem/yr)	2.2
10-year fatal cancers	8.8×10^{-3}
Noninvolved Workforce[c]	
Average worker dose (mrem/yr)[b]	2.6 to 32
10-year risk of fatal cancer	1.0×10^{-5} to 1.3×10^{-4}
Total dose (person rem/yr)	3.0 to 250
10-year fatal cancers	0.012 to 1.0
Total Site Workforce[d]	
Dose (person-rem/yr)	5.2 to 252
10-year fatal cancers	0.021 to 1.0

[a] The involved worker is a worker associated with operations of the deep borehole complex. The estimated number of badged involved workers is 168.

[b] The radiological limit for an individual worker is 5,000 mrem/yr (10 CFR 835). However, DOE has also established an administrative control level of 2,000 mrem/yr (DOE 1992t); the sites must make reasonable attempts to maintain worker doses below this level.

[c] The noninvolved worker is a worker on-site but not associated with operations of the deep borehole complex. The ranges for the noninvolved workers are based on No Action values for Hanford, NTS, INEL, Pantex, ORR, and SRS. Noninvolved worker doses are shown for comparison purposes only and would not apply if the deep borehole complex were located at a separate dedicated site. The Noninvolved Workforce is equivalent to the No Action workforce.

[d] The impact to the total site workforce is the summation of the involved worker impact and the noninvolved worker impact.

[Text deleted.]

Source: LLNL 1996a for involved workers. For the noninvolved workers see Sections 4.2.1.9, 4.2.2.9, 4.2.3.9, 4.2.4.9, 4.2.5.9, and 4.2.6.9, respectively.

The annual dose to the average deep borehole complex worker would be 13 mrem; the entire deep borehole complex workforce would receive 2.2 person-rem annually. The annual dose to the average noninvolved worker would range from 2.6 to 32 mrem, depending on the borehole site (if an existing DOE site were chosen), and the annual total dose to all noninvolved workers would range from 3.0 to 250 person-rem. The annual dose to the total site workforces would range from 5.2 to 252 person-rem. The risks and numbers of fatal cancers among the different workers from 10 years of operation are included in Table 4.3.3.2.2.9–2. Dose to individual workers would be kept low by instituting badged monitoring and ALARA programs and also workers rotations. As a result of the implementation of these mitigation measures, the actual number of fatal cancers calculated would be lower for the operation of this facility.

Hazardous Chemical Impacts. The hazardous chemical impacts to the public resulting from normal operation of the deep borehole complex at the generic site are presented in Table 4.3.3.2.2.9–3. Included is the impact due only to operation of the deep borehole complex and the sites's total hazardous chemical impact. The total site impacts are provided to demonstrate the estimated level of health effects expected and the risk of cancer due to the total chemical exposures on each site. All supporting impact analyses are provided in Section M.3.

Table 4.3.3.2.2.9–3. Potential Hazardous Chemical Impacts to the Public and Workers During Normal Operation of the Deep Borehole Complex—Immobilized Disposition Alternative

Receptor	Deep Borehole Complex Generic Site	
	Facility [a]	Total Site[b]
Maximally Exposed Individual (Public)		
Hazard Index[c]	1.2×10^{-3}	1.2×10^{-3}
Cancer risk[d]	0	0
Worker Onsite		
Hazard Index[e]	0.28	0.28
Cancer risk[f]	0	0

[a] Facility=Contribution from the proposed new facility operation only.

[b] Total=Includes the contributions from the No Action and the proposed new facility operation.

[c] Hazard Index for MEI=sum of individual Hazard Quotients (noncancer health effects) for MEI.

[d] Cancer risk for MEI=(emission concentrations) x (0.286 [converts concentrations to doses]) x (Slope Factor). Where there are no known carcinogens among the chemicals emitted, therefore the calculated cancer risk is 0.

[e] Hazard Index for workers=sum of Individual Hazard Quotients (noncancer health effects) for workers.

[f] Cancer risk for workers=(emission for 8-hr) x (0.286 [converts concentrations to doses]) x (0.237 [fraction of lifetime working]) x (Slope Factor). Where there are no known carcinogens among the chemicals emitted, there are no Slope Factors; therefore the calculated cancer risk is 0.

Section M.3, Table M.3.4–47.

The HI to the MEI is 1.2×10^{-3} at the deep borehole complex site. The cancer risk to the MEI is zero (because no carcinogens are released from hazardous chemicals) at the deep borehole complex site. The HI to the onsite worker is 0.28 at the deep borehole complex generic site, and the cancer risk to the onsite worker is zero (because no carcinogens are released from hazardous chemicals).

Facility Accidents. A set of potential accidents have been postulated for a deep borehole for disposal of immobilized Pu for which there may be releases of Pu that may impact onsite workers and the offsite population. The accident scenarios considered are: earthquake, Pu storage container breakage, Pu storage container breach, pellet-grout mixing process facility fire, ceramic pellet spill, pellet-grout mix spill, dropped bucket during emplacement, failure of release-open early during emplacement, mixing system breaks pellets during bucket emplacement, pellets break during emplacement release, rupture of delivery pipe during pumped emplacement, mixing system breaks during pumped emplacement, pellets break during pumped emplacement, failure of ventilation filter, uncontrolled chemical reaction, pellet storage criticality, and pellet-grout mixing criticality. The range of consequences and risks for a set of accidents at the generic site are presented in Table 4.3.3.2.2.9–4. The estimated range of environmental data (wet to dry site) and the general public population density data (low to high density) for the generic site envelopes the site characteristics expected for the immobilized Pu disposition site.

[Text deleted.] The location of workstations, number of workers, personnel protective features, engineered safety features, and other design details affect the extent of worker exposures to accidents. Certain accidents such as fires, explosions, and criticality could cause fatalities to workers close to the accident. Prior to construction and operation of a new facility, DOE Orders require detailed safety analyses to assure that facility designs and operating procedures limit the number of workers in hazardous areas and minimize risk of injury or fatality in the event of an accident.

Table 4.3.3.2.2.9–4. Range of Accident Impacts of the Deep Borehole Complex—Immobilized Disposition Alternative

	Worker at 1,000 m				Maximum Offsite Individual				Population to 80 km				
	Risk of Cancer Fatality (per 10 yr)[a]		Probability of Cancer Fatality[b]		Risk of Cancer Fatality (per 10 yr)[a]		Probability of Cancer Fatality[b]		Risk of Cancer Fatalities (per 10 yr)[c]		Number of Cancer Fatalities[b]		Accident Frequency (per yr)
Accident Scenario	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	
Earthquake	5.7×10^{-18}	2.3×10^{-18}	5.7×10^{-14}	2.3×10^{-14}	1.2×10^{-18}	5.2×10^{-20}	1.2×10^{-14}	5.2×10^{-16}	1.0×10^{-15}	9.3×10^{-18}	1.0×10^{-11}	9.3×10^{-14}	1.0×10^{-5}
Pu storage container breakage	5.7×10^{-18}	2.3×10^{-18}	5.7×10^{-16}	2.3×10^{-16}	1.2×10^{-18}	5.2×10^{-20}	1.2×10^{-16}	5.2×10^{-18}	1.0×10^{-15}	9.3×10^{-18}	1.0×10^{-13}	9.3×10^{-16}	1.0×10^{-3}
Pu storage container breach	5.7×10^{-18}	2.3×10^{-18}	5.7×10^{-16}	2.3×10^{-16}	1.2×10^{-18}	5.2×10^{-20}	1.2×10^{-16}	5.2×10^{-18}	1.0×10^{-15}	9.3×10^{-18}	1.0×10^{-13}	9.3×10^{-16}	1.0×10^{-3}
Pellet - grout mixing process facility fire	5.7×10^{-18}	2.3×10^{-18}	5.7×10^{-14}	2.3×10^{-14}	1.2×10^{-18}	5.2×10^{-20}	1.2×10^{-14}	5.2×10^{-16}	1.0×10^{-15}	9.3×10^{-18}	1.0×10^{-11}	9.3×10^{-14}	1.0×10^{-5}
Ceramic pellet spill	5.7×10^{-19}	2.3×10^{-19}	5.7×10^{-17}	2.3×10^{-17}	1.2×10^{-19}	5.2×10^{-21}	1.2×10^{-17}	5.2×10^{-19}	1.0×10^{-16}	9.3×10^{-19}	1.0×10^{-14}	9.3×10^{-17}	1.0×10^{-3}
Pellet grout mix spill	1.7×10^{-15}	6.9×10^{-16}	3.4×10^{-15}	1.4×10^{-15}	3.6×10^{-16}	1.6×10^{-17}	7.2×10^{-16}	3.1×10^{-17}	3.0×10^{-13}	2.8×10^{-15}	6.0×10^{-13}	5.5×10^{-15}	6.0×10^{-2}
Bucket dropped during emplacement	5.7×10^{-15}	2.3×10^{-15}	5.7×10^{-11}	2.3×10^{-11}	1.2×10^{-15}	5.2×10^{-17}	1.2×10^{-11}	5.2×10^{-13}	1.0×10^{-12}	9.3×10^{-15}	1.0×10^{-8}	9.3×10^{-11}	1.0×10^{-5}
Failure of release - opens early during bucket emplacement	2.8×10^{-14}	1.1×10^{-14}	2.8×10^{-10}	1.1×10^{-10}	5.9×10^{-15}	2.6×10^{-16}	5.9×10^{-11}	2.6×10^{-12}	4.9×10^{-12}	4.6×10^{-14}	4.9×10^{-8}	4.6×10^{-10}	4.9×10^{-5}
Mixing system breaks pellets during emplacement	5.7×10^{-14}	2.3×10^{-14}	5.7×10^{-12}	2.3×10^{-12}	1.2×10^{-14}	5.2×10^{-16}	1.2×10^{-12}	5.2×10^{-14}	1.0×10^{-11}	9.3×10^{-14}	1.0×10^{-9}	9.3×10^{-12}	1.0×10^{-3}
Pellets break during bucket emplacement release	5.7×10^{-14}	2.3×10^{-14}	5.7×10^{-12}	2.3×10^{-12}	1.2×10^{-14}	5.2×10^{-16}	1.2×10^{-12}	5.2×10^{-14}	1.0×10^{-11}	9.3×10^{-14}	1.0×10^{-9}	9.3×10^{-12}	1.0×10^{-3}
Rupture of delivering pipe during pumped emplacement	3.4×10^{-15}	1.4×10^{-15}	3.4×10^{-11}	1.4×10^{-11}	7.2×10^{-16}	3.1×10^{-17}	7.2×10^{-12}	3.1×10^{-13}	6.0×10^{-13}	5.5×10^{-15}	6.0×10^{-9}	5.5×10^{-11}	1.0×10^{-5}
Delivering pipe dropped during pumped emplacement	6.8×10^{-16}	2.7×10^{-16}	6.8×10^{-12}	2.7×10^{-12}	1.4×10^{-16}	6.2×10^{-18}	1.4×10^{-12}	6.2×10^{-14}	1.2×10^{-13}	1.1×10^{-15}	1.2×10^{-9}	1.1×10^{-11}	1.0×10^{-5}
Mixing system breaks pellets during pumped emplacement	6.8×10^{-15}	2.7×10^{-15}	6.8×10^{-13}	2.7×10^{-13}	1.4×10^{-15}	6.2×10^{-17}	1.4×10^{-13}	6.2×10^{-15}	1.2×10^{-12}	1.1×10^{-14}	1.2×10^{-10}	1.1×10^{-12}	1.0×10^{-13}
Pellets break during pumped emplacement release	6.8×10^{-15}	2.7×10^{-15}	6.8×10^{-13}	2.7×10^{-13}	1.4×10^{-15}	6.2×10^{-17}	1.4×10^{-13}	6.2×10^{-15}	1.2×10^{-12}	1.1×10^{-14}	1.2×10^{-10}	1.1×10^{-12}	1.0×10^{-13}
Failure of ventilation filter	3.4×10^{-18}	1.4×10^{-18}	3.4×10^{-13}	1.4×10^{-13}	7.2×10^{-19}	3.1×10^{-20}	7.2×10^{-14}	3.1×10^{-15}	6.0×10^{-16}	5.5×10^{-18}	6.0×10^{-11}	5.5×10^{-13}	1.0×10^{-6}
Uncontrolled chemical reaction	5.7×10^{-18}	2.3×10^{-18}	5.7×10^{-13}	2.3×10^{-13}	1.2×10^{-18}	5.2×10^{-20}	1.2×10^{-13}	5.2×10^{-15}	1.0×10^{-15}	9.3×10^{-18}	1.0×10^{-10}	9.3×10^{-13}	1.0×10^{-6}
Pellet storage criticality	1.4×10^{-10}	6.2×10^{-11}	1.4×10^{-5}	6.2×10^{-6}	2.9×10^{-11}	1.0×10^{-12}	2.9×10^{-6}	1.0×10^{-7}	6.3×10^{-9}	3.3×10^{-11}	6.3×10^{-4}	3.3×10^{-6}	1.0×10^{-6}

Table 4.3.3.2.2.9–4. Range of Accident Impacts of the Deep Borehole Complex—Immobilized Disposition Alternative—Continued

	Worker at 1,000 m				Maximum Offsite Individual				Population to 80 km				
	Risk of Cancer Fatality (per 10 yr)[a]		Probability of Cancer Fatality[b]		Risk of Cancer Fatality (per 10 yr)[a]		Probability of Cancer Fatality[b]		Risk of Cancer Fatalities (per 10 yr)[c]		Number of Cancer Fatalities[b]		Accident Frequency (per yr)
Accident Scenario	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	
Pellet-grout mixing criticality	1.4×10^{-10}	6.2×10^{-11}	1.4×10^{-5}	6.2×10^{-6}	2.9×10^{-11}	1.0×10^{-12}	2.9×10^{-6}	1.0×10^{-7}	6.3×10^{-9}	3.3×10^{-11}	6.3×10^{-4}	3.3×10^{-6}	1.0×10^{-6}
Expected risk[d]	2.8×10^{-10}	1.2×10^{-10}			5.9×10^{-11}	2.0×10^{-12}			1.3×10^{-8}	6.6×10^{-11}			

[a] The risk values are calculated by multiplying the probability of cancer fatality (for the worker at 1,000 m or the MEI) or the number of cancer fatalities (for the population within 80 km) by the accident frequency and the number of years of operation.

[b] Increased likelihood of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the incident has occurred.

[c] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

[d] Expected risk is the sum of the risks for each accident over the 10-year lifetime of the facility.

Note: The impacts shown are the maximum for the reference sites. All values are mean values.

Source: Calculated using the source terms in Tables M.5.2.8.1–3 and M.5.2.8.1–4 and the MACCS computer code.